A METHODOLOGY FOR WARGAMING

STANO SYSTEMS

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PREFACE

In the effort to develop an optimum surveillance, target acquisition, and night observation (STANO) system for integration into the Army, numerous studies must be conducted. Many of these studies will use some form of wargaming to provide the data necessary for discrimination between alternative systems. In developing wargames or computer simulations to support the play of wargames, systems analysts must derive methodologies which will allow the portrayal of STANO systems with the degree of accuracy required by the evaluation to be made.

This paper provides sytems analysts with a general methodology which may be used in the evaluation of STANO systems. The methodology may be used in evaluating any desired variations in materiel, doctrine, organization, or environment. Although presented as an aid to wargaming, the methodology may prove useful to any researcher as a means of explaining the relationship of materiel, doctrine, and organization as they function in a STANO system.

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CHAPTER I

BACKGROUND

INTEGRATION OF STANO INTO THE ARMY

In 1969, the Army undertook a high priority program to consolidate the tremendous advances in technology which are applicable to the Army's surveillance, target acquisition, and night observation activities. These activities were, for convenience's sake, given the acronymic name of STANO.[1] The emphasis that the Army expected the STANO program to receive can be deduced from some of the actions taken at Department of the Army to insure implementation of the program.

STANO Systems Manager

A STANO Systems Manager (STANSM) was designated by the Chief of Staff to manage the project at DA level. The STANSO is in the Office of the Chief of Staff, reporting to the Vice Chief of Staff.[2] This DA level managerial technique in the past has been used only for high-visibility, high priority projects such as Main Battle Tank 70 and the Advanced Aerial Fire Support Platform projects. The STANSM

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[1]LTG George I. Forsythe, "Army Keynote Address," Sensor Aided Combat Systems (U) Symposium Proceedings, 6-7-8 January 1970 (Washington: National Security Industrial Association, 1970), p. 28-5.

[2]BG William B. Fulton, "STANO Systems Management," ibid., p. 29-5.

is charged with the task of insuring the development, production, and field testing of the systems and programs necessary to provide a STANO system for the Army.[3]

STANO Master Plan

A STANO Master Plan (STANMAP) was published by DA to regulate the rapid integration of STANO into the Army. In addition to establishing a top-level steering group chaired by the Vice Chief of Staff, the STANMAP directs all DA staff agencies and all major commands to establish STANO offices and STANO points of contact to provide rapid coordination of STANO matters. The STANMAP also provides the program guide for the development and evaluation of alternative STANO systems.[4]

Project MASSTER

The Mobile Army Sensor Systems Test, Evaluation, and Review project (Project MASSTER) was activated at Fort Hood, Texas, in October, 1969, with the primary mission of planning and conducting tests and evaluations of STANO systems and materiel. The project is commanded by the Commanding General, III Corps, who reports to the Office of the Chief of Staff. Troops to support the MASSTER tests and evaluations are provided from III Corps units.[5]

INITIAL STANO STUDIES AND EVALUATIONS

The effort to integrate STANO technology into the Army has

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[3] Ibid., p. 29-4. [4] Ibid., pp. 29-5, 29-6.

[5] MG John Norton, "Project MASSTER," ibid., p. 33-1.

given rise to numerous studies and evaluations. The initial efforts in this area have been of necessarily limited scope, and none have been truly systems oriented. Most studies have addressed a single item of STANO equipment or a single type of equipment, and field evaluations have been greatly handicapped by the limited availability of equipment. An examination of some of the initial efforts to design and evaluate STANO systems reveal typical limitations. The following discussions are necessarily brief and general in nature due to the security classification of the studies. For complete information, the reader is directed to the referenced documents for each evaluation.

High Gear

High Gear was an evaluation of several equipment items which could be called a STANO subsystem.[6] The conclusions concerning the level of assignment of the equipment, and its density, appear valid within the constraints of the evaluation, but these conclusions may vary when other STANO devices with different capabilities are added to the system.[7]

STANO II

STANO II was basically intended to provide data which would lead to the selection of the optimum basis of issue, doctrine, and organization for STANO within a battalion.[8] Equipment was insufficient to support the various mixes to be evaluated, and time did not allow the

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[6] U.S. Army Combat Developments Command Experimentation Center, Final Report, Field Evaluation High Gear (U), June 1969, pp. I-8, I-9.

[7] Ibid., p. I-19.

[8] U.S. Army Combat Developments Command Institute of Special Studies, STANO II Plan of Test (U), 1969, p. 2.

number of repetitions required to exercise the organizational and doctrinal options. Because of these shortages, the evaluation provided little more than comments concerning the effectiveness of individual STANO items.[9]

STANO III

The purpose of STANO III was to assess the doctrine, organizations, concepts, basis of issue and logistic support required by an infantry division in its employment of unattended ground sensors to enhance its combat capability in Southeast Asia.[10] Since the evaluation dealt only with unattended sensors, it assessed only a part of the full STANO system. Because of the necessity of not interfering with combat operations, the evaluation was restricted in both flexibility and detailed analysis.[11]

FUTURE STUDIES

Many more studies and evaluations will be made before candidate STANO systems emerge which approach an optimum of cost-effectiveness. The large number of STANO items from which to choose, and the various organizational and doctrinal options which may be used in low, mid, or high-intensity warfare make the development of these candidate systems a formidable task. Many of the studies and evaluations to be made will

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[9] Test Directorate, STANO Evaluation, STANO II, Part I Final Report of Test (U) (Fort Bragg, N.C.: 18th Airborne Corps, 1970), p. 3-6.

[10] Army Concept Team in Vietnam, Final Report STANO III Unattended Ground Sensor Combat Evaluation (U), 20 September 1970, p. I-1.

[11] Ibid., p. I-6.

rely upon some form of wargaming to determine how varying doctrine, organization, and materiel will impact upon the effectiveness of the STANO system. These games, and models to support them, will be developed by analysts, and the adequacy of the games will be largely dependent upon how well the analyst understands the functioning of a STANO system.

RESEARCHING STANO

An analyst's first activity in the preparation of a wargame is research. In researching STANO, the analyst finds many competing doctrinal, organizational, and materiel approaches to an improved STANO system. The battlefield Information Control Center (BICC)[12] concept, the Tactical Operations System (TOS),[13] Integrated Battlefield Control System (IBCS),[14] and the STANO II options are a representative few of the many concepts with which the STANO system is intimately related. These frequently conflicting concepts may be initially confusing to the analyst, but they present no major problems in developing a wargame methodology, since the concepts are usually well documented, and because the purpose of the game normally is to discriminate between these alternative concepts.

As he continues his research, however, the analyst finds huge

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[12] U.S. Army Combat Developments Command Intelligence Agency, Intelligence-75, Volume II (U), 1968, pp. G12-G23.

[13] BG Wilson R. Reed, "Applications of Automatic Data Processing in the Field Army," Proceedings, Army 85 Concept Symposium (U) (Washington: Electronic Industries Association, 1969), pp. 317-320.

[14] BG William B. Fulton, "Integrated Battlefield Control System," Sensor Aided Combat Systems (U) Symposium Proceedings, 6-7-8 January 1970 (Washington: National Security Industrial Association, 1970), pp. 31-1 through 31-8.

amounts of factual information concerning individual items of STANO equipment and their capabilities, but little organization of this information into categories about which general conclusions may be drawn. In other words, there is no disciplined structure for the available information. In at least two areas, this lack of structure creates gaps which the analyst must span before his work is completed.

Limited Scope of Existing Methodologies

As previously indicated in this chapter, under "Initial STANO Studies and Evaluations," the methodologies of early STANO related studies are not readily adaptable into a methodology for wargaming the STANO system. These methodologies were adequate for their purposes, but the problems which they addressed were limited, and they were therefore less flexible than the methodology must be for a STANO system. In order to encompass the alternative approaches to a STANO system, the methodology should be flexible enough to accommodate changes in the component parts of the system: organization; doctrine; and materiel.

Inadequate Classification of Sensors

In order to insure sufficient flexibility in a methodology to allow all current or foreseeable sensors to be used, the analyst must determine the factors that make sensors differ from one another. These factors, once identified, will provide a framework for the categorization of sensors. Typical of the imbalance between technology and doctrine in the STANO field is the fact that over two hundred STANO items are being evaluated by STANSM, yet only rudimentary attempts have been made to categorize sensors in a manner

that is usable to the analyst.[15] The use of terms such as "night vision devices" and "unattended ground sensors" is widespread, and the terms are useful in generalized discussions, but they are of little use in building a methodology. Under "night vision devices," for instance, we find items based upon rather divergent technologies, such as ordinary binoculars, image intensification devices, and thermal imaging devices. Under "unattended ground sensors," we find an amazing array of technological differences. The only thing that unattended ground sensors have in common seems to be that they are sensors, and are "unattended."

Reference to a pair of documents which should provide the most definitive guidance on classification of sensors--the USAMC Electronics Command STANO Catalog, and FM 31-2 (Test), STANO Doctrine--indicates that an analyst who requires a categorization of sensors suitable for use in a wargame methodology will have to categorize the sensors for himself. The STANO catalog categorizes sensors under such broad headings as Night Vision, Radars, and Unattended Ground Sensors.[16] FM 31-2 has much information concerning the differences in sensors, but attempts to categorize only the sensing technologies used in the various sensors.[17] This categorization is useful to some degree, but is primarily intended as a framework for an explanation to

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[15] U.S. Army Electronics Command, Catalog of Surveillance, Target Acquisition, and Night Observation (STANO) Equipment and Systems (U), April 1971, pp. D1-E1.

[16] Ibid., pp. i-v.

[17] Department of the Army, FM 31-2 Test, Surveillance, Target Acquisition, and Night Observation (STANO) Doctrine, June 1970, pp. 4-1 through 4-5.

the tactician, not to the analyst. Additionally, the categorization is not comprehensive, since at least one kind of sensor--the breakbeam sensor--cannot be fitted into the categorization in FM 31-2.

THE THESIS

An analyst's research in the STANO area will undoubtedly encounter any number of problems, depending upon the scope and nature of the specific problem that he is investigating. It is highly probable, however, that all analysts will encounter the two problems listed above: the lack of an adequate classification of STANO items; and the lack of an adaptable methodology which treats a complete STANO system. In order to assist analysts in future research efforts, particularly with reference to these two problem areas, the remainder of this paper is dedicated to an investigation of the following thesis:

> STANO systems may be described with reasonable accuracy by a simple, generalized methodology which will be useful to systems analysts as a point of departure for the development of detailed models for specific applications.

CHAPTER II

DESIGN OF THE INVESTIGATION

LIMITATIONS

Before attempting to describe the investigation to be made, it will be useful to identify some of the more or less arbitrary limits that will be imposed upon the problem in an effort to limit its scope to that which may be accomplished within the time available for this research. The STANO system, as defined in FM 31-2, "is comprised of those means and materiel organic to or in support of the Army in the field (to include other Services) associated with information gathering and presentation capabilities utilized to find the enemy or facilitate night operations."[18] This rather broad view of the STANO system will be limited for the purposes of this paper by the following criteria: the human factors involved in the interpretation of sensor information, and the flow of information through an organizational structure will not be addressed; communications problems either from person to person or between sensor and readout device will be excluded; enemy countermeasures which disable sensors will not be considered; and surveillance items with high security classification (usually non-tactical in nature) will be excluded from discussion. These factors, which fall within the FM 31-2 definition,

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[18]Ibid., p. 2-1.

are important problem areas in themselves. Their exclusion is not an indication of their lack of impact upon the problem, but a recognition that this paper must select an achievable goal.

CRITERIA FOR THE METHODOLOGY

If a generalized methodology for wargaming STANO systems can be developed, it will meet several basic criteria. Since the methodology must encompass a system, it must allow variations in the three components of a system: doctrine, materiel, and organization. More specifically, the methodology must allow the use of all sensors, must allow variations in doctrine as to the placement and operation of sensors, and must allow variations in density and mix of sensors which would reflect different bases of issue. Additionally, since the system must function upon a battlefield, the methodology must allow a realistic depiction of the battlefield. To do this, the methodology must consider the environmental factors which influence the acquisition capabilities of sensors, and must allow an accurate description of the interplay of sensors and targets. Finally, the methodology must provide for a means of evaluating system effectiveness.

The foregoing criteria place some rather specific constraints upon the development of a methodology. The following constraints form the framework upon which the methodology must be built. They also provide a means for evaluating the completed methodology.

Sensor Categories

The requirement that the methodology encompass all sensors makes it impractical to address each sensor as an individual hardware

item, since over two hundred items are now involved, and the variations from a hardware stand point stagger the imagination. A more satisfactory arrangement, which insures the automatic coverage of new sensors as they are developed, and which is more meaningful from the stand point of a methodology, is to categorize sensors so that a sensor can be described in terms of the factors which influence its performance. This categorization, or classification of sensors will provide the necessary flexibility to the methodology to insure that it can use all sensors.

Flexibility and Sensitivity

In addition to allowing the use of all sensors, the methodology must be flexible enough to allow the use of various doctrines, various sensor densities, and various sensor mixes. These requirements demand that the methodology be non-restrictive in these areas, while accounting for the impact that these variations will make on the effectiveness of the system. In other words, the methodology must allow these changes to be made, and must be sensitive to them.

The requirement that the methodology provide realistic interplay between targets and sensors, and that the environment be accurately portrayed, place additional demands for flexibility and sensitivity. The methodology must allow realistic target and sensor movements, and must be sensitive to the physical aspects of the environment, such as terrain features, foliage, visibility, and a multitude of other environmental factors which have an impact upon acquisition. The impact of movements or of changes in environmental conditions should be properly reflected.

Measure of Effectiveness

The measurement of effectiveness of a system can be a difficult problem in itself. However, the limitations which this paper places upon the treatment of the STANO system simplifies the problem. Since such factors as operator alertness, speed of information dissemination, and level at which information is interpreted have been excluded, the measurement of system effectiveness can be based upon:

a. When and where is the target detected?

b. What is known about the target?

Our methodology, then, must provide the answers to these two questions.

THE INVESTIGATION

The basic limitations of the investigation have been stated, and the criteria for measuring the methodology proposed by the thesis has been established. The remainder of this paper will:

1. Investigate the properties of sensors currently under consideration for STANO systems, and attempt to classify them into meaningful categories.

2. Develop a general methodology which attempts to embrace all variety of sensors, mixes, densities, doctrines, environments, and movements, is properly sensitive to variations in any of them, and provides for the determination of system effectiveness.

3. Conclude at the determination of the effort whether or not the thesis is true, based upon the success of the investigation.

CHAPTER III

SENSOR CATEGORIES

BASIC SENSOR DIFFERENCES

A logical first step in developing a meaningful categorization of sensors is to examine those characteristics that make one sensor different from another. An immediate discovery is that sensors differ from each other in such a multitude of ways (e.g.: range, size, weight) that a more discriminating criteria for difference must be used. Meaningful areas of difference can be derived if we recall that the measure of system effectiveness proposed in Chapter II is based upon when and where the target is detected, and how much is known about it, and if we remember that an objective of the categorization is to minimize the impact of individual hardward differences upon the methodology. In this light, we realize that hardward differences such as size and weight may be considered as factors which help determine where a sensor may be located on the battlefield at a given time. Applying this kind of logic to the many sensors listed in the STANO catalog published by USAMC Electronics Command[19] indicates that the basic broad areas of difference between sensors can be defined under the following headings.

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[19]U.S. Army Electronics Command, <u>Catalog of Surveillance, Target Acquisition, and Night Observation (STANO) Equipment and Systems (U)</u>, April 1971, pp. I-1 through VIII-4.

How Sensors are Positioned

Sensors differ from one another in how they are positioned. Whether a sensor is emplaced by man, aircraft, surface vehicle, or other means has an impact on where the sensor may be found upon the battlefield. Where the sensor is found has an effect upon when and where the target is detected.

How Sensors are Operated

Sensors differ in how they are operated. If a sensor is operated automatically by the target itself, the probability of detection may be different from that of a sensor whose operator is constrained doctrinally as to periods of operation. These factors have an effect upon the detection of a target.

Coverage of Sensors

The areas which may be covered by sensors vary widely. These variances are based upon the physical characteristics of the sensors, and upon the doctrine for their use. Whether a sensor is being used for surveillance over a single point or a broad area makes a considerable difference in when a target is detected.

Sensing Technology

The sensing technologies which are used in sensors differ between the various sensors. The range of the sensor is related to the technology used. The compatibility of the sensor and the target signature is also dependent upon the sensing technology used. These factors have an effect upon when the target is detected and how much is known about it.

Availability of Information

The availability of sensor-derived information is different for different sensors. Information derived from aerial photography for example, is available only after the photographic film has been developed, while information gained from viewing through binoculars is immediately available to the operator. The availability of information has an impact when the target is detected, and upon how much is known about it.

Display of Information

The manner in which information is displayed varies from sensor to sensor. A device which provides an image of the target tells a great deal about the target. A device which provides only a visible or audible alarm of some unusual activity provides less information. How much is known about a target is heavily dependent upon the information display characteristics of the sensor.

Target Location Accuracy

The accuracy with which a sensor can locate the target varies from sensor to sensor. Some sensors are capable of locating the target within a few meters. Other sensors can only indicate the presence of a target within a rather large area. The target location accuracy of a sensor has an effect upon where the target is detected, and upon how much is known about the target. Target location is particularly important within the target acquisition portion of the STANO system.[20]

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[20] Department of the Army, FM 31-2 Test, Surveillance, Target Acquisition, and Night Observation (STANO) Doctrine, June 1970, p. 2-9.

Sensor Inactivation

Sensors may be inactivated in several ways. This area of difference is closely related to the "How Sensors are Operated" area. The manner in which a sensor is inactivated determines whether or not it is active at the time of target approach. If the sensor is not active, the target will not be detected. The factor that makes the method of sensor inactivation a basic area of difference in its own right is the capability for an automatically activated sensor to be inactivated by an operator, and for an operator operated sensor to be inactivated automatically.

DEFINITIVE CATEGORIZATION

Given the basic areas of sensor variance as described in the preceding section, we can begin a more detailed examination of sensors within the broad categories, in an effort to derive a definitive categorization. Again referring to the Electronics Command STANO catalog[21] as a reasonably comprehensive listing of sensors, and subdividing all listed sensors within the previously listed basic areas of difference, the sensor categorization emerges. Table 1 summarizes the sensor categorization in terms of category titles. The appendix demonstrates the categorization of one hundred and seven sensor devices contained in the STANO catalog (numbers have been substituted for sensor nomenclature because of security classification). The remainder of this section will explain the nature and scope

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[21] U.S. Army Electronics Command, Catalog of Surveillance, Target Acquisition, and Night Observation (STANO) Equipment and Systems (U), April 1971, pp. I-1 through VIII-4.

Table 1

Sensor Categories

How Positioned

- Mobile
  - Aerial Platform
  - Surface Vehicle
  - Man Mobile
- Static
  - Man Transportable
  - Air Transportable
  - Surface Vehicle Transportable
  - Air Dropped
  - Projectile Emplaced

How Operated

- Operator
- Automatic
- Other Sensor

Coverage

- Point
- Area
- Line
- Area Search

Sensing Technology

- Optical
- Thermal
- Radar
- Acoustic
- Seismic
- Electromagnetic
- Magnetic
- Pressure
- Disturbance
- Chemical
- Breakbeam

Information Availability

- Immediate
- On Call
- Delayed

Information Display

- Image
- Recognizable Audio
- Alarm

Location Accuracy

- Precise
- Good
- Poor

Inactivation

- Operator
- Automatic
- Other Sensor

of the categories.

How Positioned

This category describes the means by which a sensor is positioned. The major subdivisions of the category are mobile and static sensors. Mobile sensors are those which may be operated while in motion, or when their mode of transportation is halted, without significant emplacement or assembly prior to their activation. Static sensors are those which are designed for use in permanent or semi-permanent sites, or which require significant emplacement or assembly procedures prior to activation. Subdivisions of mobile sensors are: aerial platform mobile; surface vehicle mobile; and man-mobile sensors. Subdivisions of static sensors are: man transportable; surface vehicle transportable; air transportable; air dropped; and projectile emplaced.

How Operated

This category describes the means by which the sensor is activated and operated. The "operator" subdivision consists of those sensors which are turned on and operated by a human operator. The "automatic" subdivision is made up of those sensors which automatically react to a target "signature" and report their information without human assistance. The "other sensor" category is composed of sensors which are activated upon the command of another sensor, usually to confirm the identity of a target, or to gain more information of the target.

Coverage

This category describes the area within which a sensor may

detect a target. The "point" subdivision includes sensors whose range is so short, or whose field of observation is so narrow that the area under its surveillance is essentially a point. The "area" subdivision is similar to the "point" subdivision, except that the range and/or field of observation is large enough to allow the instantaneous surveillance of a significant area. When a "point" becomes an "area" is best determined by the specific requirements of the evaluation being served by the methodology. The bursting radius of an artillery shell may be a convenient definition of a "point," or the radius of an artillery concentration may prove to be a better definition for a particular application. The "line" category refers to a limited number of sensors whose area of detection on the ground is described by a line. The final subdivision is "area search." This subdivision includes all sensors which by virtue of mobility or scan capability can be used to systematically search an area.

It should be noted that sensors may be included under more than one subdivision. A hand-held observation device might be categorized as both a point coverage and an area search sensor. The manner in which it is used in any instance is a doctrinal matter, and reflects the impact that doctrinal variance can have on the effectiveness of a system.

Sensing Technology

This category describes the technology used by the various sensors in detecting a target. This is an important category, since the technology used is a major determinant in whether a sensor is capable of detecting a given target. The technology also largely

determines when and where the target is located, and how much is known about it. The "optical" subcategory includes all sensors which rely upon reflected visible or near infrared light waves from the target for detection. "Thermal" refers to those sensors which detect far infrared (thermal) waves emitted by the target. The "radar" subdivision is composed of those sensors which emit high frequency electromagnetic waves, and detect the waves reflected by the target. "Acoustic" sensors are those which detect sound waves emitted by, or caused by the target. "Seismic" sensors detect shock waves caused by the movement of the target and transmitted through the earth. Sensors in the "electromagnetic" category are those which generate an electromagnetic field, and sense changes in the field caused by the approach of the target. "Magnetic" sensors sense the passage of ferrous material through magnetic lines of flux generated by the sensor. "Pressure" sensors are those which sense changes in ground pressures caused by the passage of the target. "Disturbance" sensors are activated when broken, kicked, stepped upon, or otherwise physically disturbed by the target. "Chemical" sensors detect the presence of chemicals emitted by, or associated with the target. "Breakbeam" sensors are activated by the attenuation of a visible or invisible light beam by the target.

Information Availability

This category describes the speed at which the information is available to the first human in the information chain. The "immediate" subcategory refers to those sensors which provide information on a real time or near real time basis. The "on call" subcategory includes

sensors which record detections and report them when queried by an operator. The "delayed" subdivision is composed of sensors whose information must be stored and/or processed for a significant period of time before it is available as usable information.

Information Display

This category describes the form in which information is displayed--an area which has a great effect upon how much is known about the target. The "image" subdivision includes sensors which provide a recognizable image of the target. The "recognizable audio" grouping consists of sensors which provide audible tones which may be analyzed by an operator to determine the nature of the target. The "alarm" subcategory refers to sensors which provide only an audible, visible, or other form of alarm to signify the detection of some activity of possible interest.

Location Accuracy

This category describes the accuracy with which a sensor is capable of locating the target in relation to itself. As in the case of the "point coverage" sensor versus the "area coverage" sensor, the assignment of a sensor to one subcategory or another within this category is somewhat arbitrary, and depends upon the specific problems to be solved. Probably the most meaningful categorization can be established with reference to employment of artillery against a target, although a redefinition might be required if the evaluation of the STANO system was to be based upon a capability for delivering aimed small arms fire on a target. For purposes of this paper, we will use the following example of subcategory definitions: "Precise" location

accuracy refers to sensors which locate the target with sufficient accurancy to allow effective unobserved artillery fires to be employed; "Good" location accuracy includes sensors which provide sufficient accuracy to allow adjusted artillery fires to be used; "Poor" location accuracy refers to sensors which are unable to locate the target accurately enough to allow its engagement with artillery fires.

Inactivation

This category describes the different methods by which a sensor may be inactivated. Included in the "operator" subcategory are those sensors which are inactivated by their operators. The "automatic" grouping consists of sensors which inactivate automatically upon the occurrence of a predetermined event, such as tampering, battery failure, or termination of selected time period. The "other sensor" subcategory refers to sensors which are inactivated upon the command of another sensor, or upon the inactivation of another sensor.

SUBCONCLUSION

The preceding categorization of sensors provides a framework which encompasses existing sensors and is sufficiently flexible to accommodate new sensor developments with a minimum of modification. The sensor categorization shown in the appendix simultaneously provided both a means for deriving the categorization and a test of its flexibility. The categorization is meaningful for our use in deriving a methodology, because it deals with the functional differences of sensors, and minimizes detailed hardware differences. With this sensor categorization in hand, we can proceed with the task of developing the methodology.

CHAPTER IV

THE METHODOLOGY

THE GENERAL SURVEILLANCE PROBLEM

In Chapter II, the criteria for the desired methodology required that the methodology provide for the use of all sensors, that it allow variations in doctrine, sensor mixes, and sensor densities, that it provide for realistic portrayal of environment and realistic interplay between sensors and targets, and that it provide for a measurement of effectiveness. The best way to guarantee that a methodology will provide the flexibility and realism demanded by these criteria is to have the methodology reflect the real-world sequence of events between sensors and targets which leads to the detection (or non-detection) of the target. In describing such a sequence, the sequential statements must be general in nature to provide the flexibility necessary to insure the inclusion of all sensors, doctrines, and environments. The resulting description might accurately be described as a statement of the general surveillance problem. The following description of the interaction of target and sensors is believed to be a statement of the general surveillance problem and will be tested for adequacy in this respect as it is expanded and examined through the remainder of this chapter.

Relative Sensor-Target Motion

Assuming a starting situation in which no detection has yet

occurred, relative movement of the target toward the sensor must take place before detection will occur. On a battlefield, this movement may be composed of target movement, sensor movement, or a combination of the two. Movement occurs in three dimensions, since terrain and the use of aerial platforms introduce changes in altitude in addition to motion in a horizontal plane. The relative motion between sensors and target may eventually lead to the next step in the sequence.

Target Detection

Detection occurs when the target moves within the effective range of a sensor that is compatible with the target signature. The effective range of the sensor is dependent upon the technology incorporated into the sensor, how it is being operated, and the environment. The compatibility of the sensor is a function of its technology.

Information Display

After detecting the target, the sensor displays information concerning the target. How much information is displayed, and how it is displayed, is dependent upon the type of sensor.

THE GENERAL SURVEILLANCE PROBLEM AS A METHODOLOGY

The general surveillance problem as stated above is of no great value as a methodology, since it is so general that it fails to provide a "how-to" approach with the detail necessary to provide a step-by-step analysis of target detection. However, the general statement can be expanded into a more detailed statement which may be

used as a methodology. As examination of the three basic steps in a target detection indicates that these basic steps may logically be divided into six analysis-oriented, more detailed steps.

Relative Sensor-Target Motion

The first step in the statement of the general surveillance problem was relative movement between sensor and target. This motion was caused by the movement of sensor, target, or both, and consisted of movement in three dimensions. This general statement requires no further subdivision to provide required detail, but may be restated in a form which is convenient for a step-by-step analysis. Step One in our methodology will be: "An incremental change in location of the target relative to the sensing means."

Target Detection

The second basic step in the general surveillance problem statement was the detection of the target. Detection occured when a target fell within the effective range of a sensor which was compatible with the target signature. This general statement appears subject to being broken down into more specific steps associated with 'effective range' and "compatibility." To assist a step-by-step analysis, however, another step should be inserted. When an incremental range change has occured as a result of Step One, a detailed analysis of all sensors in the sensor array will be required to determine if detection has occured. To decrease the number of sensors which must be closely examined after each incremental movement, Step Two is: "Determination as to whether the target is within the possible range of one or more sensors." Taking the next easiest

analytical step for Step Three: "Determination of the compatibility of the target signature with the sensing capabilities of the in-range sensors." Step Four will be: "Determination of the effective sensor ranges against the target under the specific environmental conditions." The arrangement of steps two through four in this sequence will allow the easiest and fastest analysis of detection by eliminating first, through the simplest computation, those sensors which cannot make the detection.

Information Display

The third basic step in the statement of the general surveillance problem was the display of information. Display of information occurs following detection. The display consists of all information that is obtained by the type of sensor or sensors that made the detection. The general step does not require subdivision but will be rephrased for Step Five: "Tabulation of target data."

Sixth Step

Subdivision of the three basic steps of the general surveillance statement has provided five sequential steps with more detail. The five steps determine if a detection has occurred. If no detection occurs, a step is needed to close the loop and return the analysis to Step One for another round. If a detection is made, and the target is not eliminated, surveillance of the target will continue. Again, the loop must be closed. Step Six will be: "Assessment of target status, and if target still exists, repetition of the six steps."

Review

The preceding paragraphs have outlined the six steps in the

statement of the surveillance problem. These steps provide a basis for the methodology we seek. Table 2 summarizes the format of the methodology in the form of a flow diagram. The methodology will be expanded and its use explained in the following section.

USE OF THE METHODOLOGY IN ANALYZING TARGET DETECTION

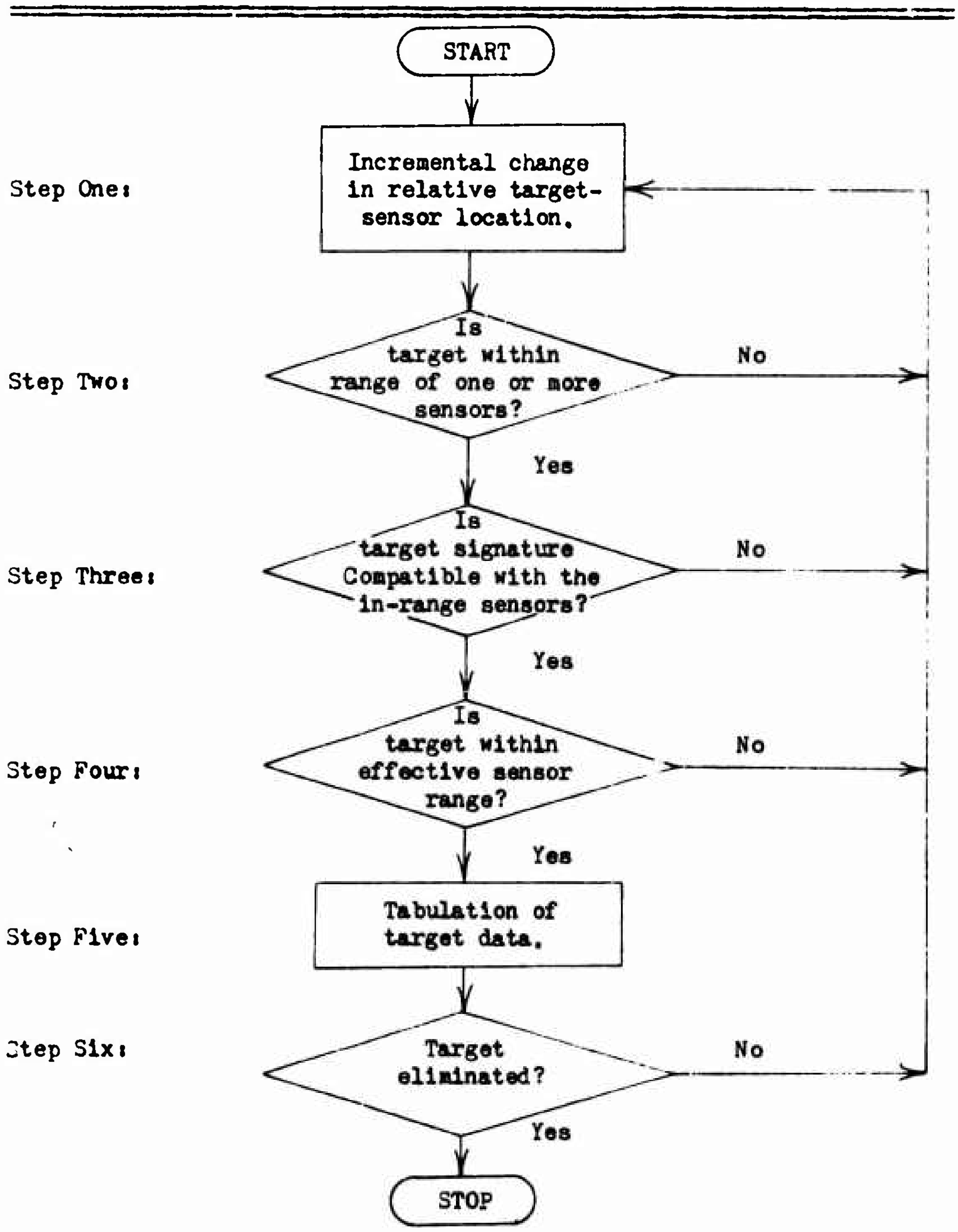
The methodology as stated may very well be a comprehensive statement of the problem, but its effectiveness as a tool to assist the analyst remains to be demonstrated. In order to use the methodology for an analysis or evaluation of alternative STANO systems, the analyst must be provided with a key to the relationship of sensors, targets, environment, and doctrine within the methodology. Armed with information concerning the impact of sensor design, environmental conditions, target signature, and doctrinal options upon the methodology, the analyst can use the methodology as a basis for the design of wargames or computer simulations. These games and/or simulations can be designed to provide detailed target detection analysis to the degree required by the problem to be solved. This section, then, will provide a discussion of how sensors, targets, doctrine, and environment relate to the methodology, in an effort to provide both an expanded explanation of the methodology and a justification of its rationale.

Step One

In making an incremental range change between target and sensors, let us assume a single moving or stationary target and an

Table 2

The Methodology Expressed as a
Flow Diagram



array of moving and/or stationary sensors. A "single target" may be a single individual, a single item, or a group of individuals and/or items which presents itself as a single sensing to the sensor. A "sensor' is construed to be any device or thing sensitive to a target signature, and capable of displaying its reaction to the target in a form recognizable to humans. In other words, "sensor" will include everything from the human eye through the most sophisticated electronic devices. Let us further assume that the target is initially beyond the range of all sensors in the sensor array, requiring that movement of the target or a sensor occur before detection can take place. The movements of targets and sensors are determined by both physical capabilities and doctrinal considerations.

Both targets and sensors are constrained with respect to their location, speed and direction by their means of locomotion. As indicated by the sensor categorization, sensors may be made mobile by means of aerial platforms, surface vehicle platforms, or man mobile. Obviously, where the sensor is located at a given instant, its speed, and its direction are all dependent upon the characteristics of its mode of transportation. Static sensors, too, are constrained as to location by their transportability or means of emplacement. A truck mounted radar, for instance, can only be located in a place which is accessible to the truck, while a projectile emplaced sensor can only be located within range of its launching means. Speed and direction, of course, are not properties common to static sensors. The location, speed and direction of targets is constrained in a manner identical to the sensor constraints. If mobile, a target can only move in the manner that its means of locomotion allows. If static, a target can

only be in a position indicated by its ability to be transported there.

Doctrinal considerations largely determine where sensors and targets are located, where they are going, and how fast they are moving. A doctrine which calls for surveillance of an area from a base camp location will result in a sensor array which differs greatly from an array resulting from a sensor deployment in accordance with a doctrine of area surveillance by mobile patrols. The location, speed, and direction of a target similarly depends upon where his doctrine would have him, and what it would have him do. These doctrinal options are chosen by opponents, and constitute one of the elements of the system to be evaluated.

Step Two

As previously indicated, the determination as to whether or not the target is within the possible range of one or more sensors is used as a discriminator to quickly eliminate those sensors which cannot make a detection because of inherent range limitations. Almost all sensors have a stated maximum range capability for given type targets. For those few sensors which do not have a stated range capability, maximum ranges may be derived from observed date, or, in the case of developmental items, expected performance data. The maximum range of a sensor, as used in this methodology, is that range, under ideal conditions, beyond which the probability of detection falis below a level which is deemed significant for the purposes of a specific investigation.

Sensors whose maximum range exceeds the range to the target may be capable of detecting the target. These sensors will be examined

more closely during succeeding steps of the analysis. Detection of the target is beyond the statistically significant capability of all other sensors, and they will be ignored until further movement of target or sensors places the target within their maximum range. If the target is beyond the maximum range capability of all sensors, the analysis returns to Step One.

Step Three

Every target has one or more "signatures" w[illegible] susceptible to detection. These signatures may be noise, movement, light, heat, ferrous content, ground pressures mass, or a variety of other physical phenomena. For detection to occur, a sensor must be capable of sensing one or more "signatures" common to the target. A determination of this compatibility between sensor and target signature comprises Step Three.

Each sensor is sensitive to at least one target signature. The compatibility of a sensor with the signature of the target is defined by the type of sensing technology incorporated in the sensor. The following enumeration of sensing technologies and their sensitivity to physical phenomena provide a guide to the determination of compatibility between sensors and target signatures.

1. Optical sensors[22] are sensitive to visible and/or near infrared light waves reflected by or emitted by the target and the target background.

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[22]Department of the Army, FM 31-2 Test, Surveillance, Target Acquisition, and Night Observation (STANO) Doctrine, June 1970, pp. 4-1, 4-2.

2. Thermal sensors[23] are sensitive to targets whose temperatures differ from those of surrounding objects.

3. Radar sensors[24] are sensitive to electromagnetic waves of the proper frequency reflected by a moving target or emitted by a target.

4. Acoustic sensors[25] are sensitive to audible noises created by the target.

5. Seismic sensors[26] are sensitive to shock waves generated by the target and transmitted through the earth.

6. Electromagnetic sensors[27] are sensitive to targets with sufficient mass to change the electromagnetic field surrounding the sensor.

7. Magnetic sensors[28] are sensitive to targets with signifíciant ferrous content.

8. Pressure sensors[29] are sensitive to targets which produce measurable ground pressure.

9. Disturbance sensors[30] are sensitive to targets which press upon or strike the sensor.

10. Chemical sensors[31] are sensitive to targets which are composed of, emit, or cause the emission of, specific chemical compounds.

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[23]Ibid., p. 4-2. [24]Ibid. [25]Ibid., p. 4-3.

[26]Ibid. [27]Ibid., pp. 4-3, 4-4. [28]Ibid., p. 4-4.

[29]Ibid. [30]Ibid., p. 4-2. [31]Ibid., pp. 4-4, 4-5.

11. Breakbeam sensors[32] are sensitive to targets which attenuate light waves in the visible or near infrared portion of the frequency spectrum.

Sensors which are compatible with the signature of the target are examined further in the next step of the analysis. These sensors may detect the target. Sensors which are not compatible are eliminated from further analysis in the detection of this target. If no sensors are compatible, the analysis reverts to Step One.

Step Four

The effective range of a sensor, for the purposes of this methodology, is that area within which there is a significant probability that the target will be detected under the existing environmental conditions. It should immediately occur to the analyst that the probability of detection will vary for different portions of the area effectively covered by a sensor. Most sensors, for example, have a greater probability of detecting a given target at close range than at maximum range. The technique used to express this variance in detection probability should be determined by the degree of detail desired in a particular evaluation. One technique might be to divide the effective area into portions, each portion being labeled with the average detection probability for that portion. Another technique is to label probability points within the area and to interpolate between points. Numerous other techniques may be used. These techniques are familiar to analysts, and exploration of all of them exceeds the

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[32] U.S. Army Electronics Command, Catalog of Surveillance, Target Acquisition, and Night Observation (STANO) Equipment and Systems (U), April 1971, p. A7.

purpose of this methodology. It is important, however, that we examine the factors that influence the effective sensor ranges.

One set of factors which will help determine effective sensor range falls under the heading of doctrinal considerations. These considerations might be simply stated as, "Is the sensor being operated, and if so, where is it pointed?" Sensors which are activated or inactivated by an operator are placed in operation according to a doctrine which must consider surveillance needs, operator limitations, and enemy countermeasures. Depending upon the doctrine used, sensors may or may not be operated continuously. The analyst can cope with the "on or off" problem by addressing the probability that a sensor will be operating, by using operating schedules, or by an other technique which suits the purposes of his analysis. Doctrine also prescribes the mode in which a sensor is operated, when more than one mode is available. A sensor which is used to detect targets at a single point may have a high detection probability over a small area, while the same sensor used in an area search mode may have a lower detection probability over a much larger area. The probability of detection due to mode of operation can be attacked by the analyst through the use of search pattern equations or more general probability statements, as needed.

Physical characteristics of sensors and the environment constitute the other set of factors which influence effective sensor range. Once again, a sensor may be "on" or "off" as a result of its physical characteristics. Some sensors are designed to inactivate themselves at the end of a predetermined time period. Computation of this type of inactivation presents no problem to the analyst. Some

sensors may be activated by another sensor's detection of the target. The analyst must insure that his analysis, or simulation, requires detection by the activating sensor before the dependent sensor is activated. her physical factors which influence detection are enumerated below. This enumeration does not purport to be totally comprehensive, since new factors emerge as technical experience is gained, and since the factors expressed here may be combined or subdivided to suit the particular needs of a specific evaluation. The analyst can derive computations which express the probability of detection based upon variances in these factors, and may use data from experimentations, theoretical values, or both, to provide values for his computations. Again, the techniques used by the analyst should be dependent upon the desired accuracy of the evaluation.

1. Optical Sensors:[33] dependent upon line of sight, light level, visibility, target contrast, and resolution.

2. Thermal Sensors:[34] dependent upon line of sight (excluding foliage), target temperature differential, atmospheric attenuation, resolution, and foliage attenuation.

3. Radar:[35] dependent upon line of sight (excluding foliage), target size, target configuration, target movement, background noise, and foliage attenuation.

4. Acoustic Sensors:[36] dependent upon target noise level and background noise level.

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[33] Department of the Army, FM 31-2 Test, Surveillance, Target Acquisition, and Night Observation (STANO) Doctrine, June 1970, pp. 4-1, 4-2.

[34] Ibid., p. 4-2. [35] Ibid. [36] Ibid., p. 4-3.

5. Seismic Sensors:[37] dependent upon target noise level, soil transmission factors, bond between soil and sensor, and sensor sensitivity.

6. Electromagnetic Sensors:[38] dependent upon target mass, sensor sensitivity, and target movement.

7. Magnetic Sensors:[39] dependent upon the ferrous content of the target and target movement.

8. Pressure Sensors:[40] dependent upon soil conditions and the amount of ground pressure created by the target.

9. Disturbance Sensors:[41] not subject to range variations, due to activation at zero range only.

10. Chemical Sensor:[42] dependent upon concentration of chemical at source and atmospheric conditions.

11. Breakbeam Sensors:[43] dependent only upon the passage of target through its beam.

Sensors whose effective ranges cover the target may have detected the target. Since effective range is associated with a probability, target detection can be decided for analytical purposes by using a random number generator or similar technique. Those sensors which have detected the target will be examined further. Sensors which have not detected the target will be ignored for the remainder of the round. If no sensor has made the detection, the analysis returns to Step One.

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[37]Ibid. [38]Ibid., pp. 4-3, 4-4. [39]Ibid., p. 4-4.

[40]Ibid. [41]Ibid., p. 4-2. [42]Ibid., pp. 4-4, 4-5.

[43]U.S. Army Electronics Command, Catalog of Surveillance, Target Acquisition, and Night Observation (STANO) Equipment and Systems (U), April 1971, p. A7.

Step Five

The tabulation of target data tells the analyst how much is known about the target. The amount of information that is required depends upon the use to be made of it. If the information is to be used for target acquisition purposes, the target needs to be fixed very accurately in time and space, and its identification as enemy is highly desirable. Information concerning the activity of the target is less important. Information required for general intelligence use places great importance on the identification of the target and its activity, and can afford less accuracy in target location in time and space. The adequacy of the available information will have to be judged by the analyst in the light of the requirements of his evaluation. Since the target data available from a sensing varies with different kinds of sensors, the following paragraphs will describe in general terms the information that might be available in terms of the informational elements of WHO, DOING WHAT, WHEN, and WHERE.

WHO. Optical and thermal imaging sensors are capable of distinguishing between individuals and various types of materiel items. They are also capable of identifying enemy troops and materiel under optimum conditions. Acoustic sensors allow the operator to distinguish between personnel and materiel targets, and usually allow identification of enemy targets through analysis of the acquired sounds. Radars cannot distinguish between friend and enemy except by analysis of location, but can distinguish the difference between personnel and vehicle targets either through audio analysis or by target speed. All other sensors are incapable of differentiation between friend and enemy, except through location analysis, and cannot tell the difference between personnel

and materiel targets.

DOING WHAT. Optical and thermal imaging devices are capable of describing target activity accurately. Radar can describe target activity only in terms of movement. All other sensors can reliably describe target activity only as a presence, although acoustic sensors may be able to describe target activity more accurately through analysis of acquired sounds.

WHEN. Some unattended sensors store and report all accumulated sensings on command, retaining only a general indication of the time that the sensings occured. All other sensors now in use report their sensings immediately, thereby fixing the target accurately in time. Exceptions are a few cameras which do not note the time of exposure on the film, and so fix the target only generally in time.

WHERE. The accuracy of locating targets varys from sensor to sensor. The ratings of "Precise," "Good," and "Poor" developed in the sensor categorization demonstrate their accuracy with reference to the use of artillery fire. All sensors except a few are capable of locating a target with sufficient accuracy to allow its engagement with artillery. Exceptions are area and line coverage sensors which provide no target location within the area or line covered, chemical sensors which collect samples that have drifted an unknown distance from their source, and some alarm sensors which provide only a target direction.

Step Six

Following the tabulation of target data, all that remains is to close the loop with a return to Step One for another round of detection analysis, or to stop. A target, once detected, usually remains under

surveillance until it is destroyed or until beyond our detection means. Translating this into the language of our methodology, we must determine whether the target still exists. This will usually be a doctrinal determination which is provided to the analyst. If the target has not been destroyed, the analysis returns to Step One. If the target no longer exists, the analysis ends.

CHAPTER V

CONCLUSIONS

CRITIQUE OF THE METHODOLOGY

Examination of the methodology in the context of the criteria established in Chapter II should indicate the strengths and weaknesses of the methodology as an approach to the evaluation of STANO systems. Chapter II set limits for the methodology which excluded some important factors: human factors involved in interpretation of sensor information, and the flow of information through an organizational structure where not to be addressed; communications problems, from person to person or between sensor and operator were to be excluded; enemy countermeasures which might disable sensors were not to be considered; and sensors with high security classification, which are usually non-tactical sensors, were to be excluded from the discussion. These exclusions were designed to limit the scope of the problem to an area which might be effectively researched in the time available. After the scope of the problem was identified, the criteria for the system-oriented methodology was established. The methodology was to allow the use of all sensors, allow variations in density and mix of sensors to reflect varying bases of issue, and allow variations in the doctrine which regulates the employment of sensors. It was to consider the environmental factors which influence target detection, allow an accurate description of target-sensor interplay, and provide for a means of evaluating sensor effectiveness.

These criteria should now provide the means for evaluating the methodology.

Varying Materiel, Doctrine, and Basis of Issue

The methodology provides for the use of all types of sensors through the system of functional categorization developed in Chapter III. When each sensor to be used in the system is categorized according to its functional design, its characteristics are automatically expressed in a format which insures that the sensors capabilities and limitations are properly considered throughout the analysis. The methodology allows variation in doctrine. By indicating the areas in the analysis that will be influenced by doctrine, and by permitting doctrinal options to be expressed in terms of the placement and operation of sensors, the methodology allows any conceivable doctrinal variation to be exercised. Sensor density and mix may be varied by changing the composition of the sensor array used with the methodology. These variations reflect the differences that would be obtained from various bases of issue that might be used with different Tables of Organization and Equipment.

Environmental Factors

The methodology allows the environmental factors to be portrayed with whatever accuracy is demanded by a specific evaluation. These factors are brought into play during the computation of sensor effective ranges, and include those environmental factors which significantly influence the detection ranges of the sensors being analyzed. However, there are certain to be many variables not yet discovered, or about which little is known, which also have an impact upon the capabilities of the various sensors. These additional variables should be easily

incorporable into the methodology when they are identified.

One environmental factor not considered by the methodology, and one that is difficult to deal with, is that of false alarms caused by natural phenomena.[44] These false alarms are common when alarm-type sensors are activated by the sensing of some natural occurrence which presents a signature similar to that of a target. Interpretation of false alarms must be performed by the sensor operator, and operator-sensor interface was excluded from the methodology. Since false alarms occur in real situations, but do not occur in war games and simulations, the analyst should be alerted to the existence of this factor. The analyst can then insert false alarm rates into his analysis, or can document their exclusion from consideration, thereby avoiding misleading analysis.

Target-Sensor Interplay

The methodology allows realistic interplay between target and sensors. The positioning and movement of targets and sensors is made in accordance with their physical capabilities, and within doctrinal constraints. The incremental movement of targets and sensors allows the determination of detections as they occur, and permits the exercise of doctrinal options with regard to tracking and configuration of targets.

Measurement of Effectiveness

The methodology provides for the measurement of effectiveness. Effectiveness is determined from the tabulation of target data. Since the amount of information required will vary between one evaluation

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[44] Department of the Army, FM 31-2 Test, Surveillance, Target Acquisition, and Night Observation (STANO) Doctrine, June 1970, p. B-4.

and another. the analyst may interpret the tabulated data in accordance with the demands of the evaluation.

CONCLUSIONS CONCERNING THE THESIS

The preceding chapters have examined the thesis that STANO systems may be described with reasonable accuracy by a simple, generalized methodology which will be useful to systems analysts as a point of departure for the development of detailed models for specific applications. The methodology that has been developed is relatively simple and easy to understand. It is certainly generalized, since it allows any desired degree of variation of doctrine, materiel, and organization. The methodology should prove useful to an analyst who is beginning his research of STANO systems, since it describes the functioning of a system, and the major factors which influence its functioning. The analyst should also be able to modify the methodology to meet the requirements of a specific evaluation. For these reasons, the thesis is concluded to be correct.

APPENDIX

Sensor Number[45]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Page Number	I-7	A-1	I-41	I-4	I-28	A-1	I-30	A-1	I-[illegible]	A-1	I-25	A-2	I-35	I-22	I-44	I-47	I-50	I-19	I-53	I-59	I-16	A-1	A-1	A-1	I-66	I-3[illegible]
How Positioned																										
Mobile																										
Aerial Platform	X	X	X	X		X		X		X		X		X	X	X	X	X		X				X		
Surface Vehicle					X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Man Mobile													X	X	X	X		X	X	X	X	X	X	X	X	
Static																										
Man Trans					X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Air Trans					X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Surf Veh Trans					X	X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Air Dropped																										
Proj Emplaced																										
How Operated																										
Operator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic																										
Other Sensor																										
Coverage																										
Point					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Area																										
Line																										
Area Search	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
Sensing Technology																										
Optical	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	X	X
Thermal				X					X												X	X				
Radar																										
Acoustic																										
Seismic																										
Electromagnetic																										
Magnetic																										
Pressure																										
Disturbance																										
Chemical																										
Breakbeam																										
Information Avail																										
Immediate	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
On Call																										
Delayed																										
Information Display																										
Image	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Recognizable Audio																										
Alarm																						X		X		
Location Accuracy																										
Precise		X			X	X		X		X																
Good	X		X	X			X		X		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Poor																						X				
Inactivation																										
Operator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic																										
Other Sensor																										

[45] U.S. Army Electronics Command, Catalog of Surveillance, Target Acquisition and Night Observation (STANO) Equipment and Systems (U), April 1971.

A

B

APPE

23 A-1	24 A-1	25 I-66	26 I-32	27 I-68	28 I-70	29 I-72	30 I-75	31 I-78	32 I-80	33 I-83	34 I-86	35 II-1	36 II-23	37 II-4	38 A-3	39 A-3	40 A-3	41 II-16	42 A-3	43 A-3	44 A-2	45 II-31	46 II-23	47 II-55	48 II-44	49 II-47	50 II-51	51 III-1	52 A-5	53 A-5
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B

C

APPENDIX. Categorisation of Sensors

51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
II-1	A-5	A-5	A-4	A-4	II-55	A-5	III-10	A-5	III-47	III-8	A-5	III-12	A-4	III-4	A-4	III-25	III-31	A-4	III-17	III-28	III-22	III-44	III-37	A-4	IV-50	A-5	IV-5	A-7	IV-60	IV-2
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